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POST-CRETACEOUS HISTORY OF THE MOUNTAINS OF CENTRAL WESTERN WYOMING[1]

ELIOT BLACKWELDER
University of Wisconsin

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PART I

INTRODUCTION

Subject and scope.—In this essay it is my purpose to discuss the geologic history of a part of western Wyoming, from the close of the Cretaceous period to the present. The field under consideration is limited naturally by the district which it has been my privilege to explore. For the interpretation of Cenozoic history the district is especially favorable because that era is represented by deposits of several ages, and the physiographic conditions are so varied that they afford the means of interpreting many of the later events. It is scarcely necessary to state that many of the problems which arose in the course of the study remain unsolved or but partly solved, for such is the nature of most complex questions.

Data and acknowledgments.—The data for this work have been obtained largely from my own field examination of the district for the United States Geological Survey during the summers of 1910, 1911, 1912, and 1913. In the summer of 1910 a somewhat rapid reconnaissance trip was made from Montpelier, Idaho, through Jackson Hole and the Wind River basin to Thermopolis, Wyoming. In 1911 we ascended Green River from the Union Pacific Railroad, made a brief examination of the southern part of the Wyoming Range, carefully studied the Fall River basin and the headwaters of Green River, and devoted the remainder of the season to an examination of the Gros Ventre Range and the highlands north of it. In 1912, a detailed study was made of the west slope of the Teton Range near the Idaho line. The summer of 1913 was devoted to the Owl Creek Range and the Wind River basin and Range. In this field work I have had the assistance of Messrs. J. M. Jessup, C. W. Tomlinson, Hyrum Schneider, and D. Dale Condit.

Earlier seasons in surrounding districts afforded me an opportunity to gather information which has value by way of comparison with western Wyoming. Thus the Bighorn Mountains in north-central Wyoming were studied in 1902, the Laramie Range in the southeastern part of the state in 1907–8, and the Wasatch Range of northern Utah in 1909.

In addition, some facts and many interpretative suggestions have been obtained from the writings of other students of the

NOTE.—Through oversight, the captions for figures were omitted from the first part of this article, which appeared in the preceding number of this *Journal* (pp. 97–117). These captions are given below:

FIG. 1.—General map of the district

FIG. 2.—Map showing routes traveled by the writer and companions in the summers of 1910–13.

FIG. 3.—Model representing the topography and structure of Wind River basin and vicinity as it probably existed just before the close of the Cretaceous period.

FIG. 4.—Model of folds and overthrusts produced at the close of the Cretaceous, restored approximately on the Carboniferous formations. The actual surface produced by folding even if not eroded would doubtless be of a different nature. The region included extends from the Idaho state boundary east to the Bighorn district. (The flat space in the southwest is merely blank.)

FIG. 5.—Sketch of the surface at the base of the Tertiary sediments north of Circle, as it probably appeared in early Eocene time. (Adapted from a photograph of the modern surface.)

FIG. 6.—Pinyon conglomerate containing irregular sandstone lenses. Hackamore Creek in the Mount Leidy highlands.

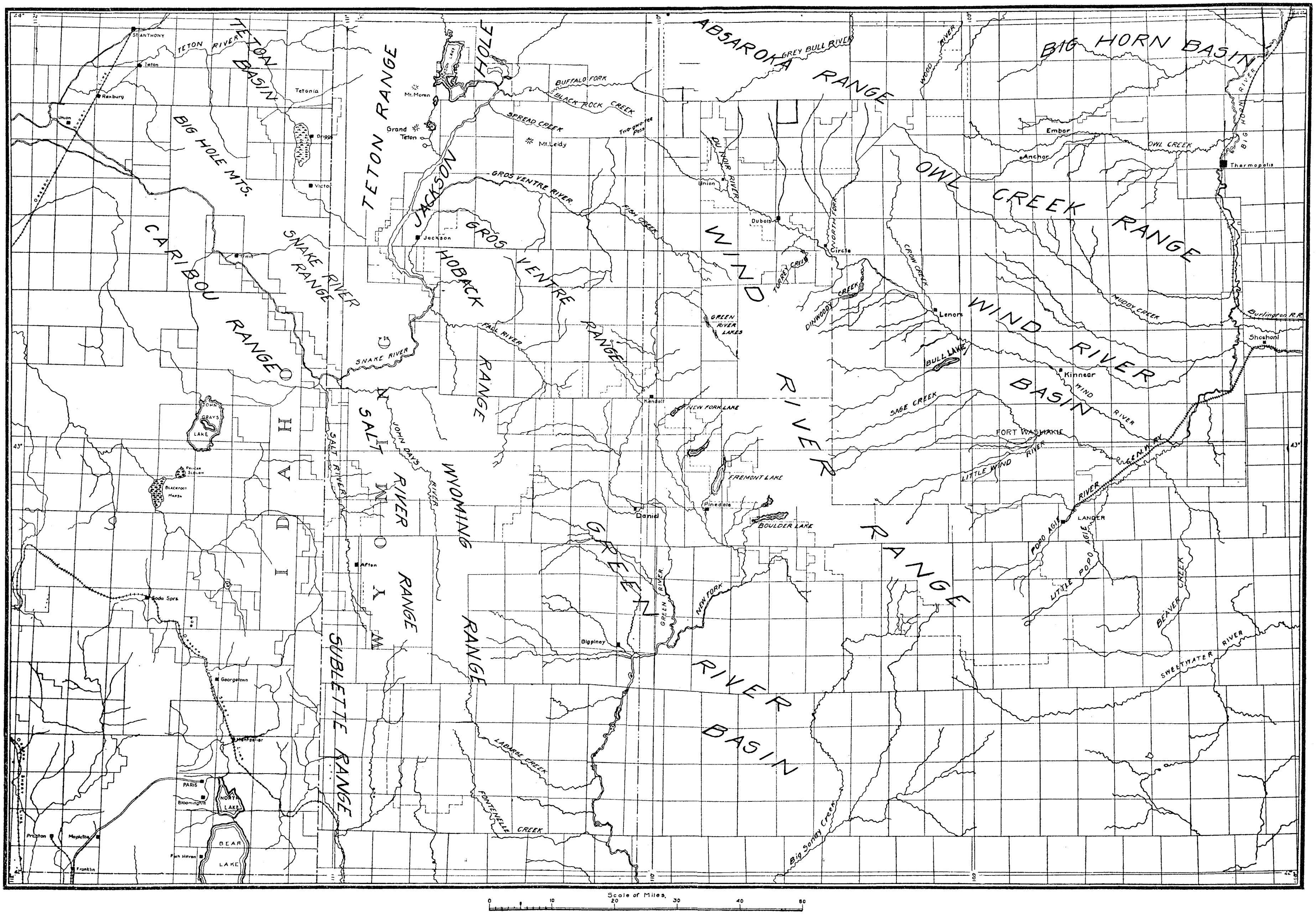
FIG. 7.—Stereogram of part of the Wind River basin and vicinity as they may have appeared after the deposition of the Eocene and Oligocene sediments.

FIG. 8.—Folded Eocene beds at Indian Meadows, near Circle. All the strata exposed belong to the typical "Wind River" clays. Drawing from a photograph.

FIG. 9.—Photograph and diagram of the fault near the mouth of Dinwoody Creek.

FIG. 10.—Diagram of the apparent relations of the Eocene conglomerate to the Paleozoic along the south side of the Gros Ventre Range.

FIG. 11.—Stereogram of the Wind River Range and vicinity as they may have appeared (neglecting erosion) after the warping and faulting, probably of Miocene date. Cf. Fig. 7.


ABSAROKA RANGE
BIG HORN BASIN
GREY BULL RIVER
WOOD RIVER
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TETON BASIN
TETON RIVER
St. Anthony
Teton
Rexburg
Tetonia
Union
Driggs
Victor
BIG HOLE MTS.
TETON RANGE
JACKSON HOLE
Jackson Lake
Mt. Moran
Grand Teton
Mt. Leidy
BUFFALO FORK
BLACK ROCK CREEK
SPREAD CREEK
Two-gwo-tee Pass
Jackson
GROS VENTRE RIVER
GROS VENTRE RANGE
HOBACK RANGE
FALL RIVER
SNAKE RIVER
SNAKE RIVER RANGE
CARIBOU RANGE
Irwin
FISH CREEK
DU NOIR RIVER
Union
Dubois
NORTH FORK
Circle
TORREY CREEK
DINWOODY CREEK
CROW CREEK
Lenore
Embar
Anchor
OWL CREEK
Thermopolis
OWL CREEK RANGE
MUDDY CREEK
Burlington R.R.
Shoshoni
WIND RIVER BASIN
WIND RIVER RANGE
BULL LAKE
Kinnear
WIND RIVER
SAGE CREEK
FORT WASHAKIE
LITTLE WIND RIVER
C. & N. W. RY.
GREEN RIVER LAKES
Kendall
NEW FORK LAKE
FREMONT LAKE
Pinedale
BOULDER LAKE
Daniel
POPO AGIE RIVER
LANDER
LITTLE POPO AGIE
BEAVER CREEK
SWEETWATER RIVER
JOHN GRAYS LAKE
Pelican Slough
Blackfoot Marsh
IDAHO
WYOMING
SALT RIVER
SALT RIVER RANGE
JOHN DAYS RIVER
WYOMING RANGE
Afton
Soda Sprs.
Georgetown
Montpelier
PARIS
Bloomington
NORTH LAKE
BEAR LAKE
Fish Haven
Preston
Mapleton
Franklin
SUBLETTE RANGE
GREEN RIVER
NEW FORK
Bigpiney
GREEN RIVER BASIN
LABARGE CREEK
FONTENELLE CREEK
Big Sandy Creek
43°
42°
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110
109
Scale of Miles
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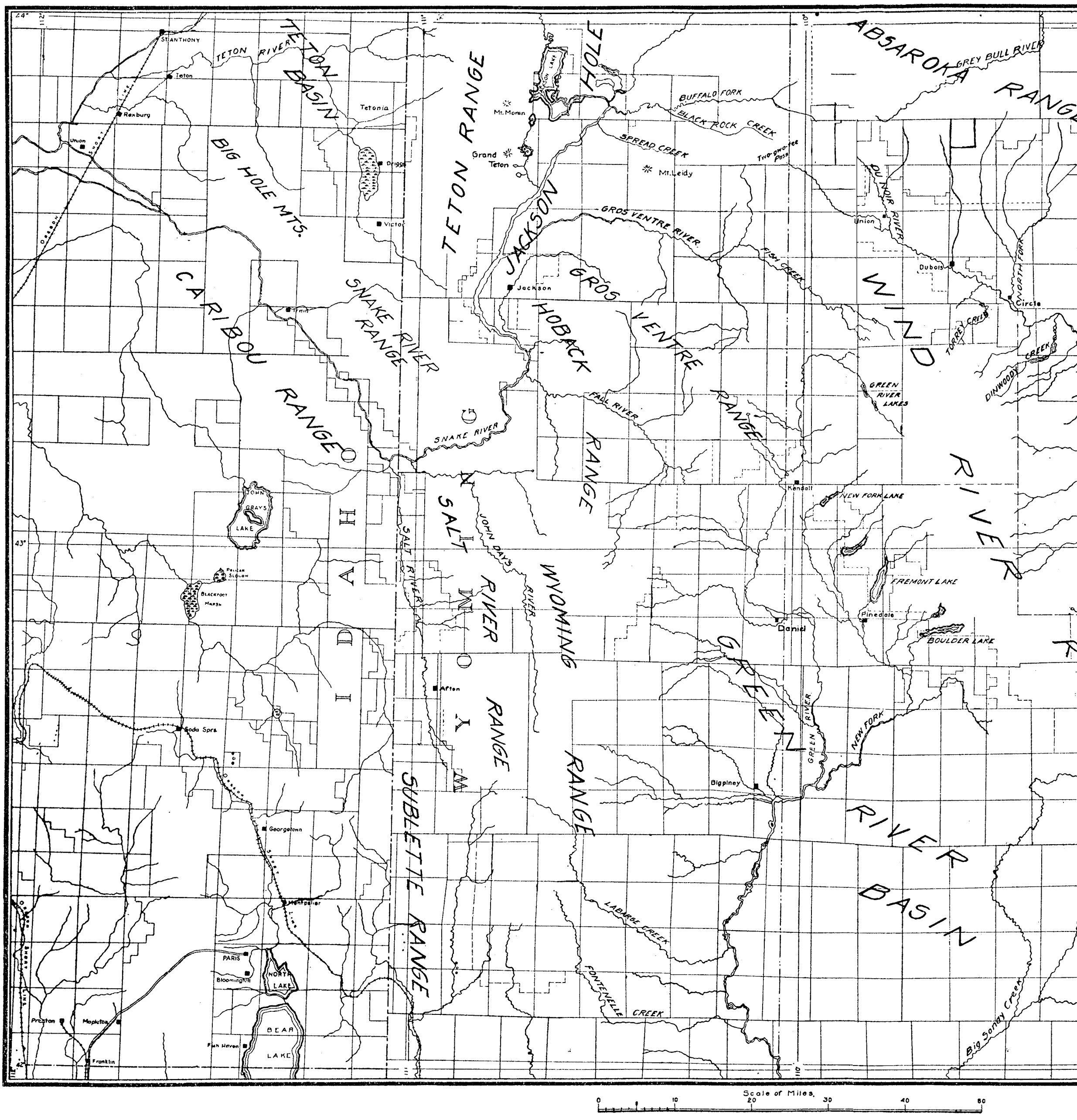
FIG. 1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Driggs
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CARIBOU RANGE
TETON RANGE
Mt. Moran
Grand Teton
JACKSON
HOLE
JACKSON LAKE
Jackson
SNAKE RIVER RANGE
SNAKE RIVER
Irwin
HOBACK RANGE
GROS VENTRE RANGE
GROS VENTRE RIVER
FALL RIVER
BUFFALO FORK
BLACK ROCK CREEK
SPREAD CREEK
Mt. Leidy
Two-gwo-tee Pass
ABSAROKA RANGE
GREY BULL RIVER
DU NOIR RIVER
Union
Dubois
NORTH FORK
Circle
TORREY CREEK
DINWOODY CREEK
FISH CREEK
WIND RIVER
GREEN RIVER LAKES
Kendall
NEW FORK LAKE
FREMONT LAKE
Pinedale
BOULDER LAKE
Daniel
JOHN GRAYS LAKE
PELICAN SLOUGH
BLACKFOOT MARSH
IDAHO
WYOMING
SALT RIVER RANGE
SALT RIVER
JOHN DAYS RIVER
WYOMING RANGE
Afton
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Georgetown
Montpelier
PARIS
Bloomington
NORTH LAKE
BEAR LAKE
Fish Haven
Preston
Mapleton
Franklin
SUBLETTE RANGE
GREEN RIVER
NEW FORK
Bigpiney
GREEN RIVER BASIN
LABARGE CREEK
FONTENELLE CREEK
Big Sandy Creek
OREGON SHORT LINE
44°
43°
42°
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Scale of Miles.
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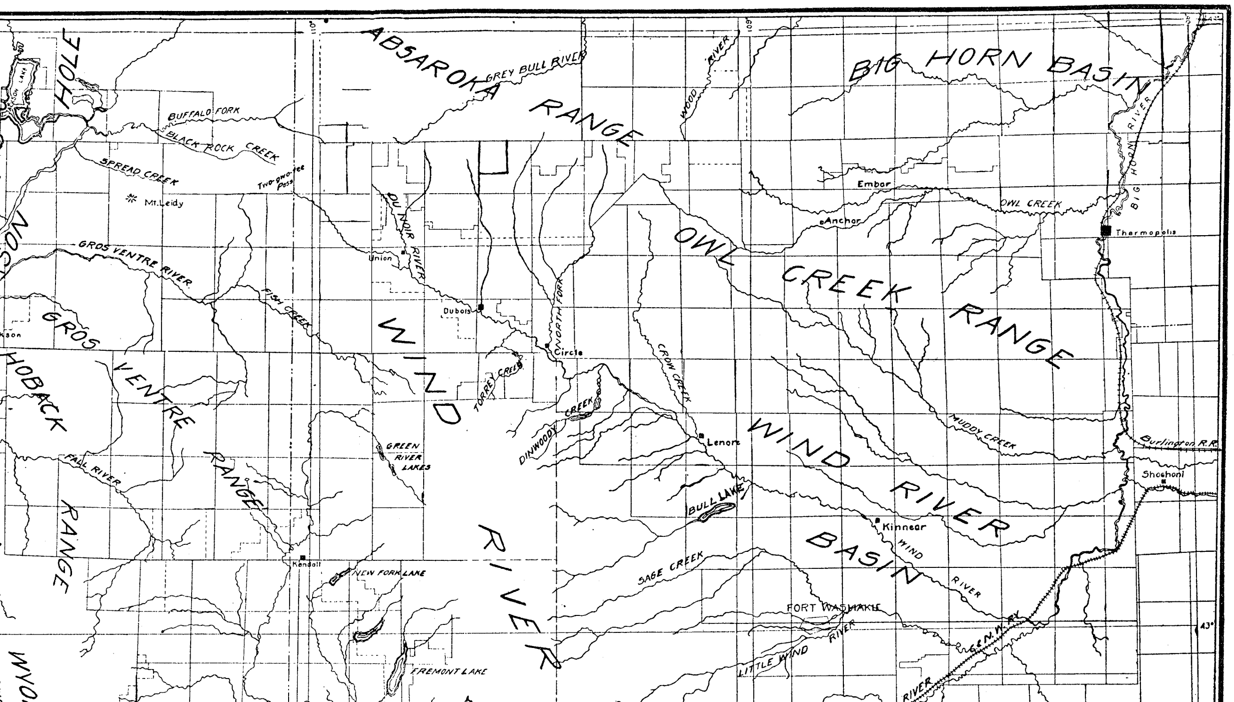
FIG. 1


HOLE
ABSAROKA RANGE
GREY BULL RIVER
WOOD RIVER
BIG HORN BASIN
BIG HORN RIVER
BUFFALO FORK
BLACK ROCK CREEK
SPREAD CREEK
Two-gwo-tee Pass
Mt. Leidy
DU NOIR RIVER
Union
Embar
Anchor
OWL CREEK
Thermopolis
GROS VENTRE RIVER
OWL CREEK RANGE
FISH CREEK
Dubois
NORTH FORK
Circle
GROS VENTRE RANGE
HOBACK
WIND RIVER RANGE
TORREY CREEK
CROW CREEK
DINWOODY CREEK
GREEN RIVER LAKES
Lenore
WIND RIVER BASIN
MUDDY CREEK
Burlington R.R.
Shoshoni
FALL RIVER
BULL LAKE
Kinnear
WIND RIVER
Kendall
NEW FORK LAKE
SAGE CREEK
FORT WASHAKIE
LITTLE WIND RIVER
C. & N. W. RY.
43°
FREMONT LAKE
Pinedale
Daniel
BOULDER LAKE
POPO AGIE RIVER
LANDER
LITTLE POPO AGIE
BEAVER CREEK
WYOMING RANGE
GREEN RIVER
NEW FORK
Bigpiney
GREEN RIVER BASIN
SWEETWATER RIVER
LABARGE CREEK
FONTENELLE CREEK
Big Sandy Creek
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109
108
Scale of Miles.
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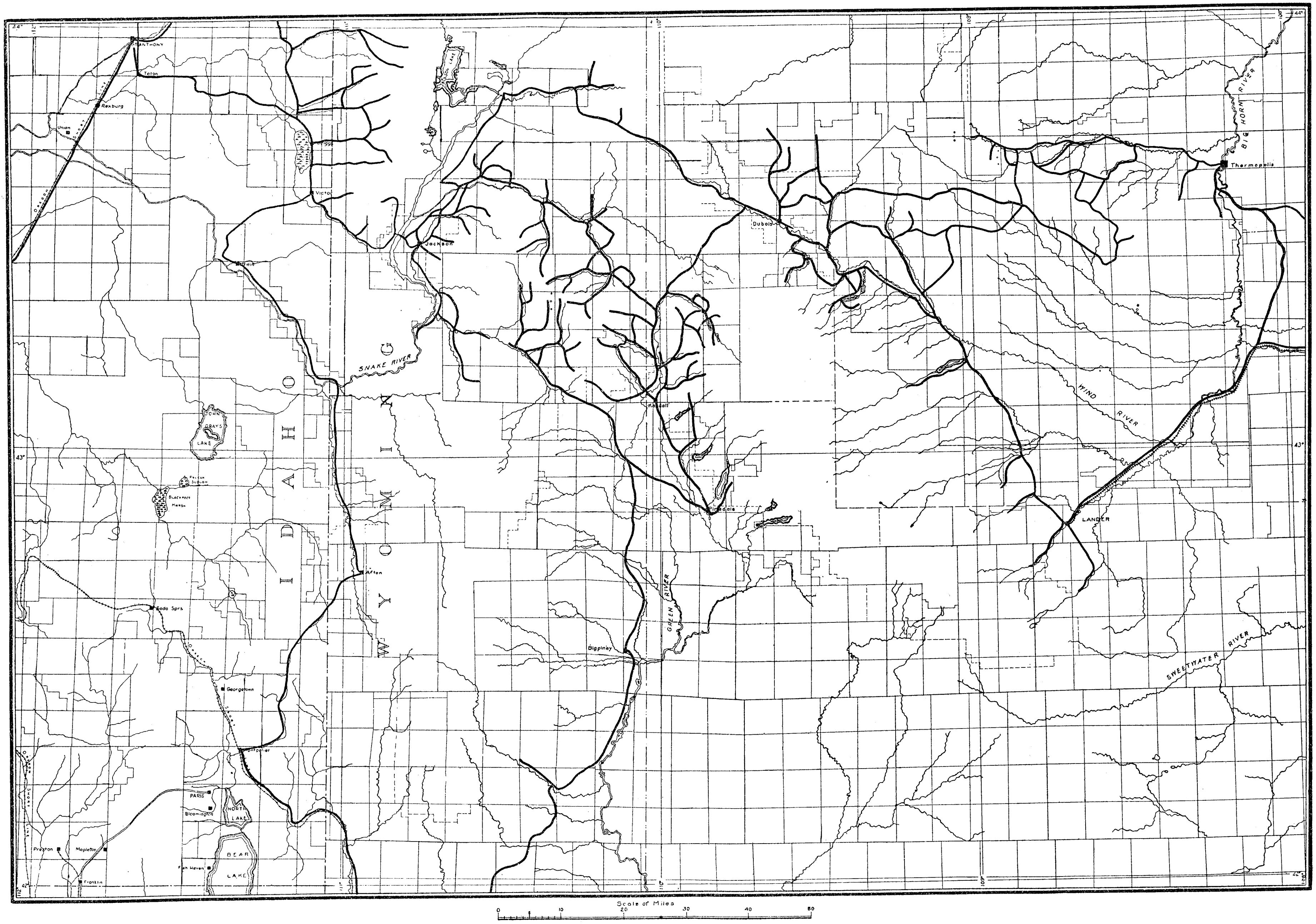
Fig. 1


44°
112°
111°
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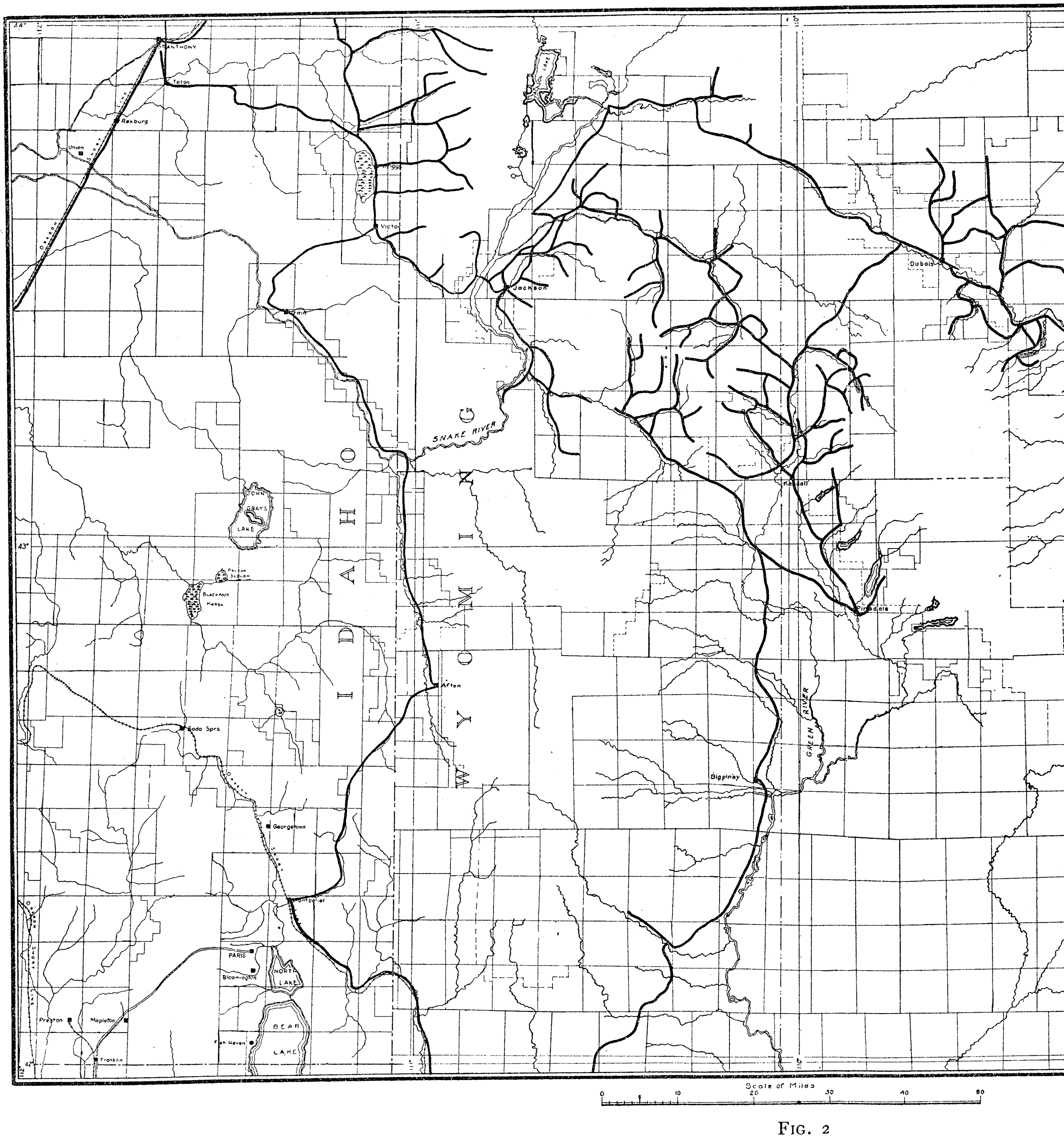
St. Anthony
Teton
Rexburg
Union
Oregon Short Line
Driggs
Victor
Jackson
Jackson Lake
Irwin
Snake River
John Grays Lake
Pelican Slough
Blackfoot Marsh
I D A H O
W Y O M I N G
43°
Soda Sprs.
Afton
Georgetown
Montpelier
Paris
Bloomington
North Lake
Bear Lake
Fish Haven
Preston
Mapleton
Franklin
42°
Dubois
Kendall
Pinedale
Big Piney
Green River
Wind River
Lander
Big Horn River
Thermopolis
Sweetwater River
Scale of Miles
0
5
10
20
30
40
50

Fig. 2


44°
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Irwin
Jackson
JACKSON LAKE
SNAKE RIVER
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WYOMING
JOHN GRAYS LAKE
PELICAN SLOUGH
BLACKFOOT MARSH
Soda Sprs
Georgetown
Montpelier
PARIS
Bloomington
NORTH LAKE
BEAR LAKE
Fish Haven
Preston
Mapleton
Franklin
Afton
Dubois
Kendall
Pinedale
GREEN RIVER
Bigpiney
Scale of Miles
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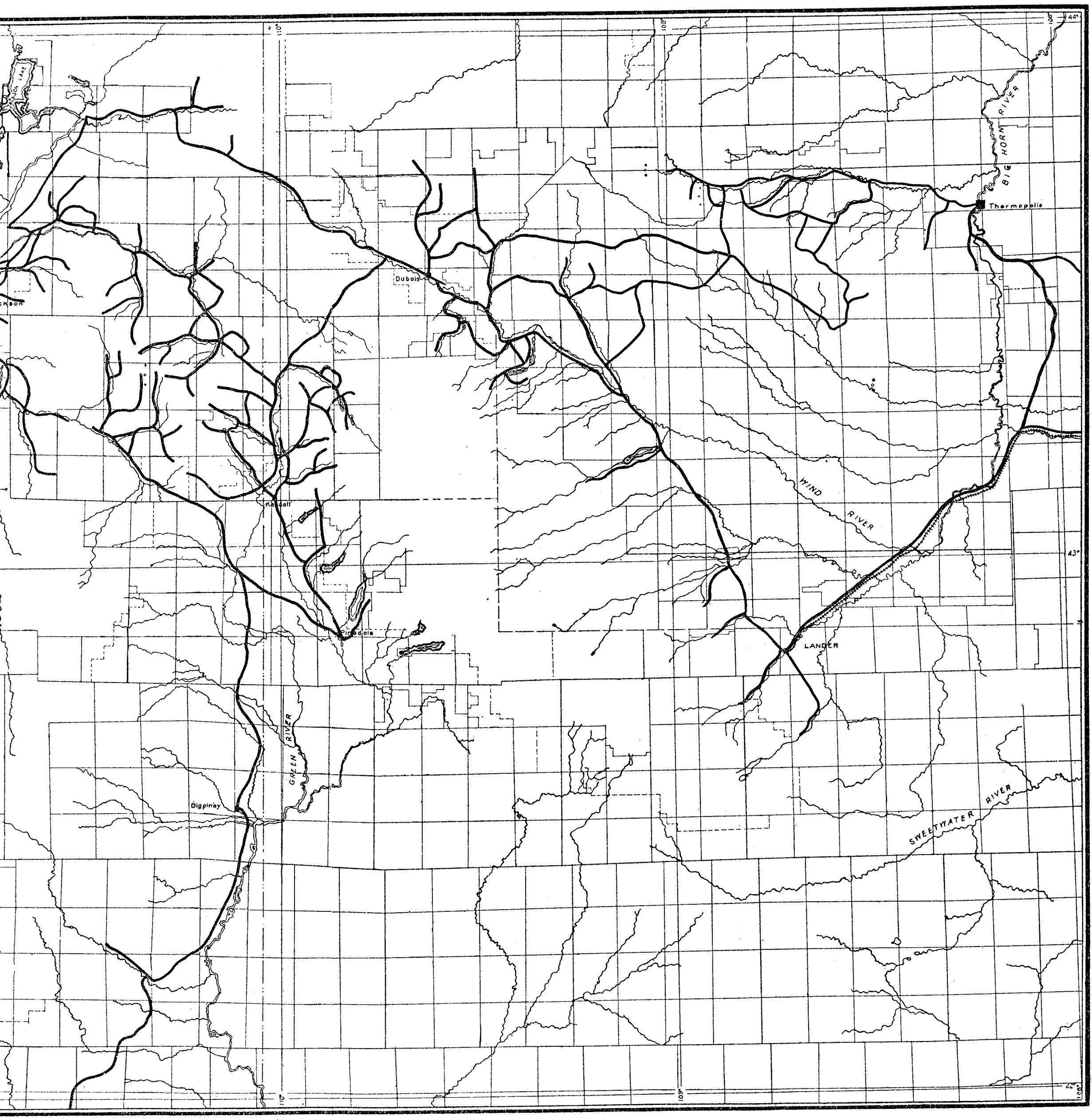
FIG. 2


110°
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BIG HORN RIVER
Thermopolis
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Kendall
Pinedale
WIND RIVER
LANDER
GREEN RIVER
Bigpiney
SWEETWATER RIVER
Scale of Miles
0
5
10
20
30
40
50

FIG. 2

Rocky Mountains, and especially from papers on districts outside the one immediately considered.

Bibliography.[1]

A. EARLY EXPLORATIONS

1. Fremont, Lieutenant John C. On the expedition to the Rocky Mountains in 1841. A general account of the Wind River Range and the adjacent Wyoming plateaus, but there is very little strictly geologic information.

B. TERRITORIAL SURVEYS

1. U.S. Geological and Geographical Survey of the Territories ("Hayden Survey"), 1872–79. The geological exploring parties in immediate charge of Bradley, Comstock, St. John, and Endlich, and under the general supervision of F. V. Hayden, made the first thoroughgoing reconnaissance of western Wyoming and parts of adjacent states. Considering the dangerous and unsettled character of the country, the lack of previous knowledge, and the short time that could be devoted to each district, the results obtained by these parties are remarkable and deserve the highest praise. The work of Orestes St. John I have found especially trustworthy. The members of these parties made a fairly good topographic map of the district and reinforced it with perspective sketches which not only take high rank for their artistic merit, but are geologically accurate. They correctly ascertained the long sequence of rock formations and interpreted the structure of the ranges with but few mistakes. In their voluminous reports one may find many suggestions about the geologic history of the district here considered, and although some of these suggestions have not been sustained by later studies, many of them will probably stand indefinitely. Altogether, the Hayden reports contain the only comprehensive and detailed account of the geology of western Wyoming that has been written.

C. SHORTER PAPERS ON SPECIAL QUESTIONS OR ON SMALL PARTS OF THE DISTRICT

1. Eldridge, G. H. "Reconnaissance in Central Wyoming." *U.S. Geol. Survey, Bull. 119*, 1894. Brief notes on the Wind River region, with the first mention of folds affecting the Tertiary strata.
2. Weeks, F. B. "A Reconnaissance in Jackson Basin," abstract in *Science*, N.S., IX (1899), 454.
3. Woodruff, E. G. "The Lander Coal Field," *U.S. Geol. Survey, Bull. 316*, 1907, pp. 242–43. A mere note.

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[1] Only such papers are here listed as have a direct bearing either upon the geology of the district in question, or upon the problems of the Cenozoic era in adjacent parts of the Rocky Mountain region.

4. Baker, C. L. A report, thus far unpublished, on the west end of the Wind River Range. In this paper there is described for the first time the Wind River peneplain. It doubtless contains many other data relating to the subject of this thesis (work done in 1908–9).
5. Blackwelder, Eliot. "Phosphate Deposits of Western Wyoming," *U.S. Geol. Survey, Bull. 430*, 1911, pp. 84–113. A brief account of the general reconnaissance of the district in 1910. Questions of post-Cretaceous history and the origin of physiographic features are briefly touched upon here and there.
6. Wallace, D. "Saddle and Camp in the Rockies," *Outing*, June, 1911. Incidentally describes the remarkable Gros Ventre slide.
7. Woodruff, E. G. "The Lander Oil Field," *U.S. Geol. Survey, Bull. 452*, 1911, pp. 1–36. Includes brief notes on the origin of the existing topography.
8. Woodruff, E. G., and Winchester, D. E. "Coal Fields of the Wind River Region, Wyoming," *U.S. Geol. Survey, Bull. 471*, 1911, pp. 516–64.
9. Baker, C. L. "Notes on the Cenozoic History of Central Wyoming," *Bull. Geol. Soc. Am.*, XXIII (1912), 73–74. Abstract of a paper read at the San Francisco meeting of the Cordilleran section, 1911.
10. Blackwelder, Eliot. "The Gros Ventre Slide: an Active Earth Flow," *Bull. Geol. Soc. Am.*, XXIII (1912), 487–92.
11. Westgate, L. G., and Branson, E. B. "The Later Cenozoic History of the Wind River Mountains, Wyoming," *Jour. Geol.*, XXI (1913), 142–59. A general interpretation of physiography of the eastern part of the range only.

D. REPORTS ON ADJACENT REGIONS, WHICH CONTAIN INFORMATION ABOUT THE SUBJECT OF THIS THESIS

1. Holmes, W. H. "Glacial Phenomena in Yellowstone National Park," *American Naturalist*, 1881.
2. Hague, Iddings, Weed, and others. "Geologic History of the Yellowstone National Park," *Smiths. Inst., Ann. Rept.*, 1891–92, pp. 133–51.
3. ———. "The Age of the Igneous Rocks of the Yellowstone National Park," *Am. Jour. Sci.*, 4th Ser., II (1896), 445–57.
4. ———. "Yellowstone Park Folio," *U.S. Geol. Survey*, No. 30, 1896.
5. ———. "Yellowstone Park," *U.S. Geol. Survey, Monograph 32*, Part 2, 1899.
6. Russell, I. C. "Geology and Water Resources of the Snake River Plain in Southern Idaho," *U.S. Geol. Survey, Bull. 199*, 1902.
7. Schultz, A.R. "Coal Fields in a Portion of Central Uinta County, Wyoming," *U.S. Geol. Survey, Bull. 316*, 1906, pp. 212–41.
8. Darton, N. H. "Geology of the Bighorn Mountains, Wyoming," *U.S. Geol. Survey, Prof. Paper 51*, 1906.
9. Fisher, C. A. "Geology of the Bighorn Basin," *U.S. Geol. Survey, Prof. Paper 53*, 1906.

10. Loomis, F. B. "Origin of the Wasatch Deposits," *Am. Jour. Sci.*, 4th Ser., XXIII (1907), 356–64.
11. Veatch, A. C., and Schultz, A. R. "Geology of Southwestern Wyoming," *U.S. Geol. Survey*, *Prof. Paper 56*, 1907.
12. Sinclair, W. J., and Granger, W. "Eocene and Oligocene of the Wind River and Bighorn Basins," *Bull. Am. Mus. Nat. Hist.*, XXX (1911), 83–117.
13. ———. "Notes on the Tertiary Deposits of the Bighorn Basin," *ibid.*, XXXI (1912), 57–67.
14. Sinclair, W. J. "Some Glacial Deposits East of Cody, Wyoming, and Their Relations to the Pleistocene Erosional History of the Rocky Mountain Region," *Bull. Geol. Soc. Am.*, XXIII (1912), 731 ff.
15. Umpleby, J. B. "An Old Erosion Surface in Idaho," *Jour. Geol.*, XX (1912), 139–47. Also review by E. Blackwelder, *ibid.*, XX (1912), 410–14, and reply in *ibid.*, XXI (1913), 224–31.

POST-CRETACEOUS GEOLOGIC HISTORY

Antecedent conditions.—In order to understand the effects produced by the various events and changes after the Cretaceous period, the reader should recall the general character of events before that time and particularly the conditions which had been brought about at the close of the Mesozoic era. These will be outlined without evidence or argument.

The oldest rocks of the district, generally referred to the Archean system, were folded and metamorphosed, and subsequently worn down to a peneplain before the middle of the Cambrian period. Beginning with the Cambrian and extending on through all of both Paleozoic and Mesozoic eras, sediments were spread over this peneplained surface until it had been buried to a depth of many thousand feet. Most of these sediments were deposited in the sea, but noteworthy portions were laid down upon land. Occasionally there were short episodes in which the region was subject to erosion, but these periods were not accompanied by orogenic disturbances and served to reduce the strata but little. The variety of sedimentary rocks thus produced is shown in the accompanying columnar section, and the importance of the varying erodability of the different beds will be better appreciated when the discussion of the modern physiographic forms is undertaken.

Since the latest and thickest of these deposits are partly marine and extend more or less uniformly over the entire district—except where subsequently eroded from the crests of the anticlines—it is tolerably safe to assume that western Wyoming, near the close of the Cretaceous period, was a nearly level plain of aggradation very near sea-level, and wholly devoid of outcrops of the Paleozoic and older rocks (Fig. 3). It is deemed unnecessary to apologize here for disregarding the ancient view that each area of Archean outcrops has been an island ever since the Cambrian.

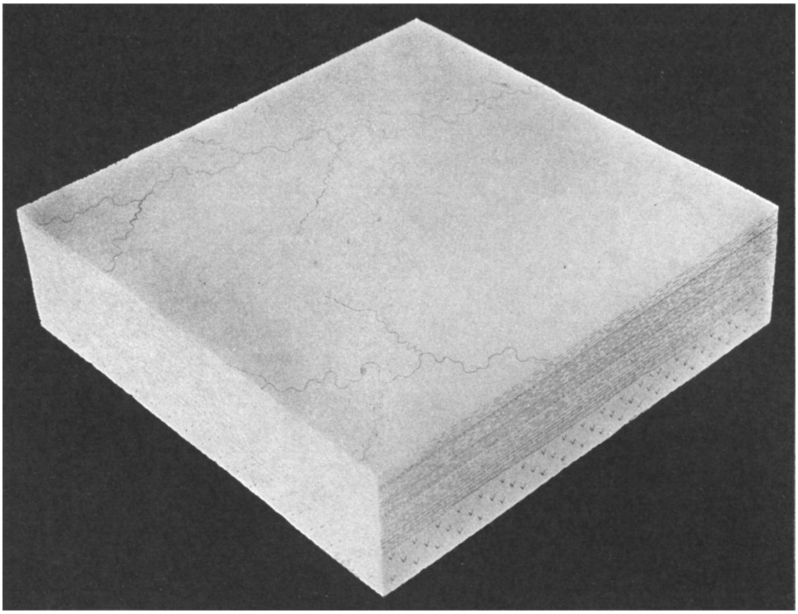

FIG. 3

Post-Cretaceous orogenic disturbance.—The Cretaceous and underlying strata have been compressed into a series of folds which generally trend northwestward through central Wyoming, and bend around to the south in the southwest part of the state. The prevailing structures in the district are open anticlines and synclines oversteepened on the southwest sides. Some of the largest folds, such as the Wind River and Gros Ventre anticlines, broke along their southwest flanks and formed overthrusts of large displacement. The most intense folding in this district generally is to be found on the lower sides of these overthrusts. South and southwest of Jackson Hole most of the folds are much more closely appressed, and the strata generally stand upright. It is a fact worth noting that this deformation was apparently not accompanied by volcanic activity within the region under consideration. I have attempted to show by means of a stereogram (Fig. 4) the general character of the folds and faults produced at this time as they might have appeared if they had been completed without being eroded. The effects of subsequent warping, faulting, and erosion have been eliminated. It is probable that there are more folds in the district than are shown on this model, for in other parts of the Rocky Mountains sharp folds in the Cretaceous rocks are occasionally revealed in canyons which locally cut through the superficial Tertiary cover.

TABLE I

CONDENSED TABLE OF FORMATIONS

Age	Character	Thickness in Feet	Description
Quaternary	Superficial deposits	1–500	Glacial drift, talus, landslides and earth-flows, river gravel and silt, loess, and residual soils
Tertiary (slightly disturbed)	Volcanics	Over 4,000	Stratified agglomerate and tuff with a few lava flows
	Wind River formation and associated strata	1,500 to 6,000	Largely clay and soft sandstone with local conglomerates and lava beds
Mesozoic (folded)	Shale and sandstone	6,000 to 10,000	Largely shale and clay with many beds of sandstone of which a few are thick and massive. Occasional thin layers of limestone, coal, and chert
Paleozoic (folded)	Limestone, etc.	2,000 to 3,500	Largely limestone or dolomite, some beds very massive and thick. Interbedded with shale, thin limestone, sandstone, and chert
Archean (?)	Metamorphic and igneous	Indefinite	Massive gneisses and some schists, with granitoid intrusions

The geologic age of the folding may be roughly ascertained without difficulty, but to determine it with a high degree of accuracy and to measure its duration are not feasible on the basis of the facts obtained in this district alone. The youngest beds involved in the folding are of the Montana group, the age of which is well established by marine fossils as middle Upper Cretaceous. Still younger strata, which now stand in a nearly vertical attitude in the canyon of Buffalo Fork, have yielded plant remains, identified by Dr. F. H. Knowlton as belonging to the Fort Union flora. Elsewhere in Wyoming it is reported[1] that the Fort Union and other formations which are correlated with it have been folded to the same degree as the underlying marine Cretaceous strata and are overlain in angular unconformity by the Wasatch Eocene and equivalent formations. However, in some of these districts the Cretaceous rocks are decidedly more folded than the Fort Union beds. This has been most clearly worked out in southwestern Wyoming by Veatch and Schultz.[2] The Fort Union formation and contemporaneous deposits elsewhere are generally referred to the "basal Eocene" or Paleocene,[3] although both stratigraphically and pale-

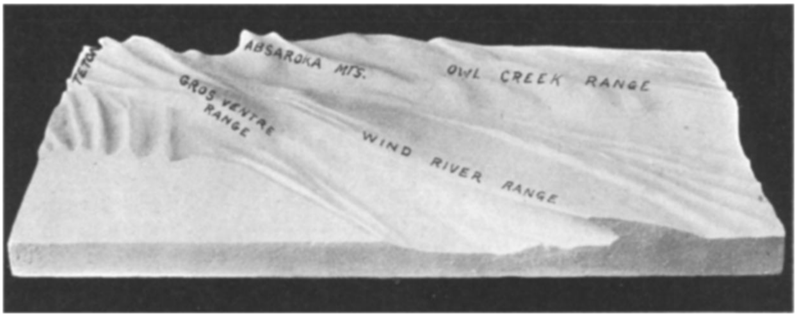

FIG. 4

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[1] Max W. Ball and E. Stebinger, *U.S. Geol. Survey, Bull. 381*, 1910, p. 194; D. E. Winchester, *U.S. Geol. Survey, Bull. 471*, 1912, p. 47.

[2] A. C. Veatch and A. R. Schultz, "Geography and Geology of a Portion of Southwestern Wyoming," *U.S. Geol. Survey, Prof. Paper 56*, 1907.

[3] Although the term "Paleocene" has not yet been sanctioned by the U.S. Geological Survey and is not in use by all American geologists, it is so much needed in this instance in order to discriminate between "Lower Eocene" and other early Tertiary rocks still older than "Lower Eocene" that it will be freely used in this paper. The term "Eocene" will refer in these pages to those strata now commonly included in "Lower," "Middle," and "Upper Eocene," or, in terms of Rocky Mountain stratigraphy, the sequence from Wasatch to Uinta formations.

ontologically they are rather closely related to the underlying Cretaceous. Following current usage in referring these formations to the base of the Tertiary system, it appears that the principal deformation occurred after the laying-down of the Paleocene series, although in some parts of the Rocky Mountains an important orogenic movement had preceded the Paleocene.

The oldest strata which were not affected by this particular episode of deformation within the limits of the district belong to the early Tertiary series, represented east and southeast of Jackson Hole by the Pinyon conglomerate, in Green River valley by the Green River formation and associated strata, along Wind River by the Wind River formation, and in the Bighorn basin by the so-called "Wasatch" beds. Mammalian and plant fossils found at various points in these districts are said to prove that the early Tertiary strata are Eocene and that the sequence generally, although not everywhere, begins with the Lower Eocene or Wasatch stage. This is in harmony with conditions generally throughout the Rocky Mountains.

The old familiar fact is thus redetermined—that the folding took place between the close of the Cretaceous and the deposition of the Lower Eocene. Assuming that the strata in the canyon of Buffalo Fork, mentioned above, have been correctly referred to the Fort Union formation, it is suggested as probable that the most vigorous folding took place between the Paleocene and Eocene epochs.

Early Eocene erosion.—So nice is the adjustment of stream activities that no sooner did the post-Cretaceous folds commence to be bulged above the grade-level of their time than they were subject to erosion. The fact that they were thus eroded is amply attested by the unconformity at the base of the Eocene (Wasatch, etc.) strata. Since the latter now rest upon the trunkated edges of any and all of the Paleozoic and Mesozoic formations, and in some places even upon the Archean, it is evident that the post-Cretaceous folds were completely trunkated during the early part of the Eocene epoch.

Whether this resulted at any time in bringing the entire region to the condition of a peneplain is still an open question. The surface which was finally produced just before the deposition of the Eocene strata is, however, preserved in the sub-Eocene unconformity. Profiles of its forms can be observed along the canyon walls in several of the ranges. At some points near the west end of the Owl Creek Mountains the old land surface has recently been exhumed by the denudation of the soft Eocene clays and yet not seriously disfigured during the process (Fig. 5). This surface was post-maturely hilly upon the harder rocks, and locally retained a relief of over 1,000 feet; but, as would be expected from their unresisting character, the softer Cretaceous and Jurassic beds were generally worn down to plains. In many places the Eocene now crosses the axes of the anticlines and thus shows that the ranges had been largely worn low.

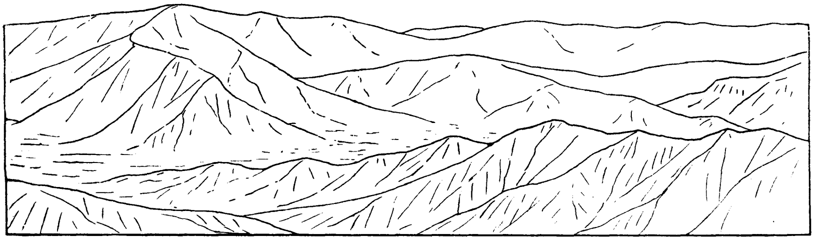

FIG. 5

Deposition of the Eocene and Oligocene formations.—Before the hilly and even mountainous parts of the early Eocene surface could be reduced to base-level, there set in more or less abruptly a change which caused the erosive processes to be supplanted in the depressions by deposition. The nature of the change is not obvious, but it may have been either a warping, which unbalanced the river systems, or a desiccation, which substituted torrential or seasonal erosion and alluviation for the slow continuous degradation of a moister epoch. Since the effects seem to have been nearly alike from Montana to Mexico, a widespread and rather uniform change is suggested. The climatic change answers this requirement, but there is uncertainty as to whether so great a thickness of sediment can be accounted for in this way. There is no question as to the competency of warping to bring about the erosion of some areas and coincident filling of others. It appears, therefore, to be the more promising factor in this case. That the new state of things continued almost, or quite, without interruption for a long lapse of time is shown by the fact that the eroded surface is now buried in some places by a thickness of apparently conformable sediments which cannot well be less than 4,000 feet thick and may easily be much more. Remnants of these beds are now to be found in all the principal lowlands of the district, such as Green River basin, Jackson Hole, and Wind River valley, and also in the Mount Leidy highlands at the northwest end of the Wind River uplift. The strata vary considerably from place to place, as they might be expected to in view of their terrestrial origin and the irregular surface upon which they were deposited.

The origin of these Tertiary deposits is not wholly obvious, and their designation as "lake-beds" by the Hayden Survey is open to grave doubt. It is safe to say that they are not marine, for instead of marine fossils they contain the remains of land plants and land mammals, as well as of freshwater fishes and mollusks. As working hypotheses we may suppose that they could have been deposited (*a*) by lakes and marshes, (*b*) by graded streams upon their floodplains, (*c*) by wet-weather streams making alluvial fans, or (*d*) by the wind upon dry land surfaces. It is not inherently improbable that each of these agencies may have played an important part. The problem compels more analysis.

The Pinyon conglomerate (Fig. 6) of the Mount Leidy highlands has already been mentioned as highly suggestive of the work of powerful aggrading streams with constantly shifting channels. It appears to be identical with deposits being made today by those means, and no other agency seems competent to produce it. The pebbles are nearly all quartzose in composition and are in large part foreign to the district. This suggests that they have been transported far, and that they are the residue of long-continued attrition. If this be granted, it may be taken to indicate that the Pinyon conglomerate was deposited largely by aggrading rivers of considerable length and power, rather than chiefly by local creeks from the surrounding mountains.

Along the flanks of the Owl Creek and Wind River mountain ranges the basal part of the Tertiary strata contains wedge-shaped beds of coarse conglomerate interleaved with the finer sediments and pinching out away from the mountains. The pebbles are ill rounded and consist wholly of rocks which outcrop near by. The lithologic varieties are many and not well assorted. These facts suggest the local deposition of alluvial fans by mountain creeks along the border of a lowland. Similar conditions exist today in the California valley.

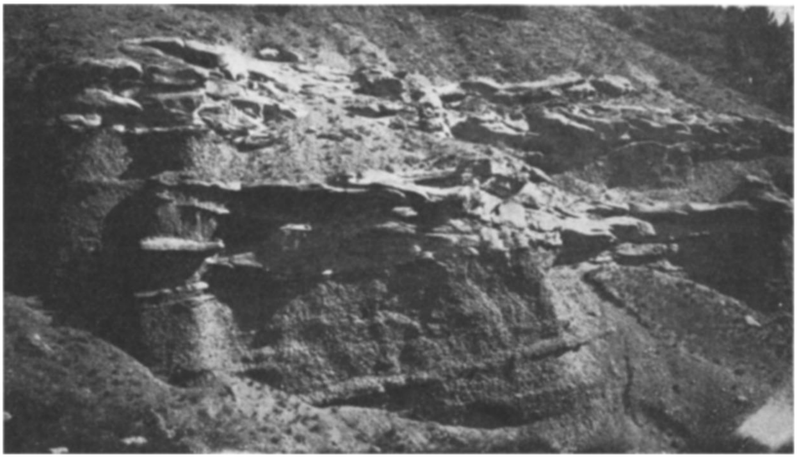

FIG. 6

Again, some small parts of the sequence have evidently been deposited in lakes, since from the valley of the north fork of the Gros Ventre River, Mr. Perry[1] of the Hayden Survey reports five successive beds of freshwater limestone containing recognizable lacustrine shells. There is equally good evidence that some of the material was laid down in marshes, for thin lignitic seams have been found in many localities, and especially in the section last mentioned. There Perry found in a single exposure no less than forty-seven beds of lignite, most of them very thin. Similar beds occur in the Bighorn and Wind River basins.

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[1] Hayden Survey report for 1878, Part 2, pp. 223–24.

The banded clays, usually of pink and gray colors, which constitute the bulk of the Tertiary beds along the head of the Gros Ventre River, throughout the Wind River basin, and in the Bighorn basin, suggest a different mode of origin. Sinclair,[1] from a careful study of these clays and their associated sandy beds in the Bighorn basin, reaches the conclusion that they are river floodplain deposits laid down under a moderately dry climate. The color banding he ascribes to alternating cycles of moist and dry climate (pp. 116–17). So regular is the repetition of their red and gray layers that an oscillating control is strongly indicated. Loomis[2] also reached the conclusion that the clays and silts of the Wasatch formation in the Bighorn basin were floodplain deposits. In this connection he called attention to the fact that, of the very large number of fossils which had been found in the beds, only 10 per cent are aquatic, whereas the most abundant forms are horses and other animals which frequent the relatively dry plains. Even the aquatic animals were turtles, crocodiles, and fishes, all of which inhabit rivers.

Such observations as I have made tend to confirm this hypothesis of floodplain deposition, under subarid or steppe conditions. The more sandy layers consist of small angular fragments of quartz, prisms and slivers of hornblende, hexagonal plates of mica, and sharp bits of feldspar. No volcanic ash was observed in the typical striped Wind River beds. The undecayed condition of the grains precludes a warm moist climate, and the prevalent reddish or pinkish color is evidence of thorough oxidation, which would have been inhibited in a cold moist climate. The general lack of abrasion suggests that the particles have not been transported very far, or at least were not worked over continuously for a long space of time. To Loomis and Sinclair's hypothesis I may add the suggestion that the Eocene sediments probably originated as regolith due to rock disintegration and eolian abrasion in a dry climate. Much of the angular quartz and feldspar dust may well be the product of sandblast action upon rock outcrops. The regolith, once formed, was probably washed down from its points of origin by temporary hill streams, sifted from the coarser fragments, imperfectly sorted mineralogically, and soon deposited on the flat bottoms of broad, intermontane basins. It is a suggestive fact that the sandy silt taken from a cut bank in the broad floodplain of Owl Creek has the same structural, textural, and mineral characteristics as some of the Wind River strata. This silt is a modern floodplain deposit in a drainage basin which does not contain outcrops of the typical Wind River strata. A mere reworking of the Eocene material in this instance is scarcely possible.

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[1] W. J. Sinclair and W. Granger, "Eocene and Oligocene of the Wind River and Bighorn Basins," *Am. Mus. Nat. Hist. Bull.*, XXX (1911), 83–117.

[2] F. B. Loomis, "Origin of the Wasatch Deposits," *Am. Jour. Sci.*, XXIII (1907), 362.

Some parts of the Tertiary sequence are obviously volcanic in origin. Thus, along the east side of Jackson Hole, there are considerable flows of andesite and rhyolite in the lower part of the formation. If we may rely upon lithologic similarity and field relations, we may correlate with these the flows which cloak the west slope of the Teton Range, although the relationship is not yet firmly established. At the northwest end of the Wind River Range, where it articulates with the mountains of Yellowstone Park, thick beds of volcanic ash and agglomerate with interbedded glassy lava flows rest upon the pre-Tertiary folded rocks, but are themselves younger than the Wind River Eocene. Traced eastward to Horse Creek, the Washakee Needles, and the valley of Owl Creek, this thick volcanic series is found to rest conformably upon the striped clays of the Wind River formation, with which they intergrade through gray, plant-bearing shales and greenish volcanic sandstones containing petrified logs. A closer examination of the volcanic beds shows that some of them are massive agglomerates, devoid of stratification, whereas other beds are distinctly stratified, cross-bedded, and occasionally interrupted by lenticular sheets of coarse gravel, suggestive of stream channels. The conditions indicated are those which would be found upon low gradient river plains adjacent to active volcanoes.

In order to place these conditions as closely as possible in chronology, it would be necessary to know the ages of all parts of this Tertiary sequence. Unfortunately, this is not fully understood. On the basis of freshwater shells, and land plant leaves which were found in the valley of the Gros Ventre River by the members of the Hayden Survey, the strata were tentatively correlated with the Wasatch of Utah. Fossil mammals from the Wind River basin[1] have recently been correlated with those of the Wind River and Uinta formations of the Eocene and with those of Lower Oligocene. In the southwest part of the Bighorn basin abundant mammals belonging to the typical Wasatch have been found by Wortmann, Loomis, Granger, and others. The beds in which they occur are so closely similar to those in the Upper Wind River valley and near the head of the Gros Ventre River that the intercorrelation of all three is strongly suggested. Since the volcanic Tertiary beds lie almost entirely at higher elevations, and, where both formations are present, at stratigraphically higher horizons than the Wind River formation, they are probably not older than Upper Eocene. Sinclair and Granger have found Lower Oligocene fossils in beds of tuff and agglomerate east of Lander. Older Tertiary beds in that vicinity do not contain volcanic materials, except for two or three beds of ash in the Middle or Upper Eocene.

In review, the evidence relating to the Tertiary sediments seems to indicate that, from the Wasatch or Lower Eocene epoch until at least the early Oligocene, west-central Wyoming was subject to a semi-arid climate in which there were, however, considerable fluctuations; that streams made widespread deposits in the lowlands; that these were largely of clay, silt, and sand but locally of gravel; and that the wind was a modifying rather than a controlling agency in the process; that lakes and marshes existed locally from time to time; and that volcanic eruptions in the western part of the district, and late in the sedimentary interval, scattered ash and cinders over much of the district. No matter what hypothesis of the origin of the Tertiary beds is adopted, it leads to the conclusion that by the Oligocene epoch the processes of sedimentation had produced one or more broad flat or gently graded plains beneath which were buried deeply the old Eocene hills and many of the lower mountains. There seems to be no means of knowing whether all the ranges were buried by the Tertiary deposits. They now cover both ends of the Wind River and Owl Creek anticlines and have evidently been eroded from large areas which they once covered. On the other hand, there seems to be no good reason to suppose that some of the principal mountain ranges did not rise above the aggraded plains somewhat as they now do in the Bonneville Lake basin of Utah (Fig. 7).

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[1] W. J. Sinclair and W. Granger, "Eocene and Oligocene of the Wind River and Bighorn Basins," *Bull. Am. Mus. Nat. Hist.*, XXX (1911), 83–117.

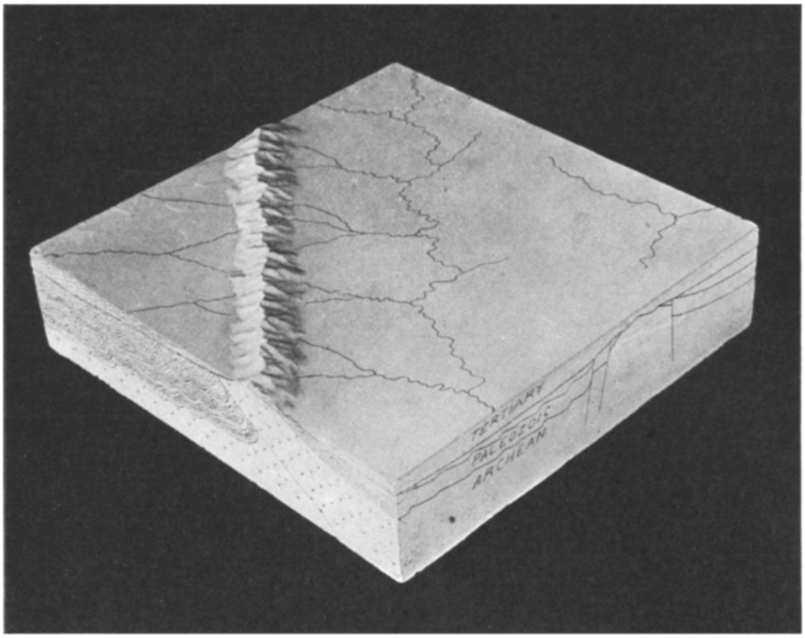

FIG. 7

Mid-Tertiary deformation.—The early Tertiary sediments no longer lie in their original almost horizontal attitude. Nearly everywhere they have been tilted gently, and in a few places bent into folds and broken by faults of large displacement. In Jackson Hole the beds of travertine or freshwater limestone with lava flows dip 10–15° toward the west. Near the forks of the Gros Ventre River the alternating sandstones and clays dip 12–14° northeastward. Near Dubois in the Wind River basin, the finely laminated Eocene clays dip 5–8° away from the Wind River Range. In the southwest part of the Bighorn basin, Sinclair and Granger observed an anticline in the Wasatch deposits, the dips being 5–7° on either limb. In the slope just east of the E. A. ranch, north of Dubois, there is a fold the southern limb of which dips at an angle of about 35°. The strongest folding I have yet seen in the Wind River beds was found on the north fork of Wind River in the southwest corner of the Kirwin quadrangle (see Fig. 8). There a relatively sharp anticline between two broad flattish synclines exhibits dips of from 5° to over 50°. Although in a few cases the dips may be initial, it is improbable that the fine clays were deposited at angles of even 5–10°.

Faulting is more common than folding in the Eocene strata. Near the mouth of Dinwoody Creek on the north side of the upper course of Wind River, a fault of several hundred feet displacement interrupts the nearly horizontal Wind River beds (Fig. 9). On the northwest side of the Teton Range a normal fault of at least 1,500 feet displacement drops the Tertiary volcanic breccias and rhyolitic flows down against Paleozoic strata. At Granite Falls, and again along Jack Creek, both on the south side of the Gros Ventre Range, a coarse conglomerate, apparently the same as the Pinyon formation farther north, has been faulted down against the Paleozoic rocks (Fig. 10). In the southern part of Jackson Hole the freshwater Eocene limestone, with its interbedded lava flows, is several times repeated in successive buttes rising above the alluvial floor of the valley. The structure is readily explained by assuming several normal faults with a downthrow on the east, but if the faults exist they are concealed by the alluvial deposits. On the west front of the Hoback Range the Tertiary beds have been faulted down against the Carboniferous. There is abundant circumstantial evidence to indicate that a great fault marks the east base of the Teton Range, cutting off the Paleozoic and Mesozoic

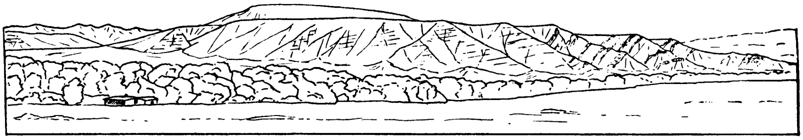

FIG. 8

succession to the east, and raising on the west a lofty wall of Archean gneiss. The exposed scarp along this fault is now more than 7,000 feet high (see Figs. 16 and 27) and the total stratigraphic throw can hardly be less than twice that amount.[1]

This deformation evidently took place later than the deposition of the conformable Eocene and Oligocene strata. If disturbances of this kind had occurred within that depositional interval, they would have caused important unconformities and changes in sedimentation, which are not in evidence. They must also have taken place long before the deposition of the older glacial drift, for the moraines have not been disturbed and on the contrary lie across fault traces along which the scarps have long since disappeared. As will be shown later, allowance must also be made

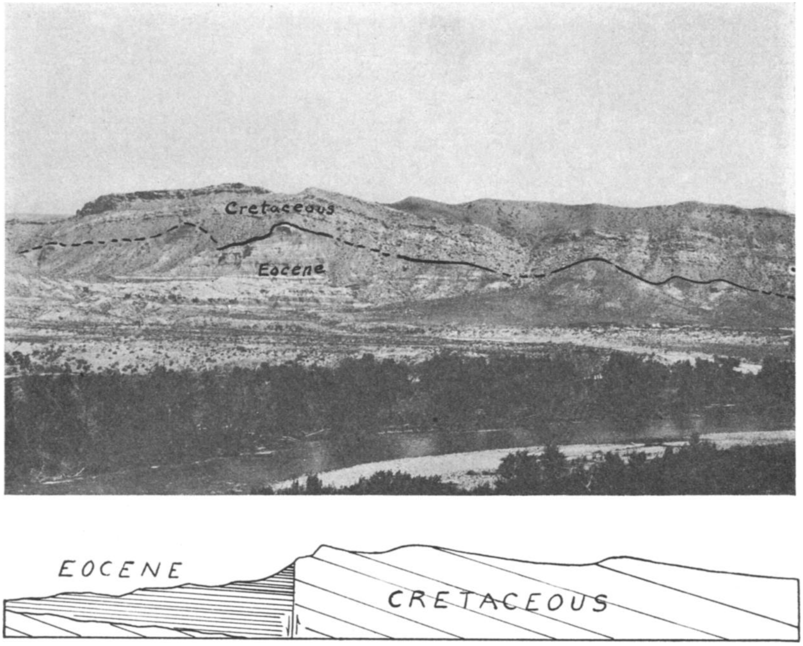

FIG. 9

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[1] For a discussion of the question whether this is a recent fault scarp or an old "fault-line scarp" (W. M. Davis, *Bull. Geol. Soc. Am.*, XXIV [1913], 187–216) see below.

here for the making of the high peneplain and the subsequent sculpturing of the modern topography before the last stage of glaciation. Since we cannot yet translate physiographic results into years or even into geologic periods, the portion of the Tertiary and Quaternary periods to be allowed for these events cannot be estimated with any degree of confidence. From the evidence within the district, then, it is justifiable to conclude only that the deformation probably followed the early Oligocene and preceded the Pleistocene.

From a general study of the tectonic disturbances at various times in the earth's history, such as the Appalachian revolution, the late Jurassic orogeny of the Pacific, and many others, it seems to be established as a general rule that deformative movements are roughly periodic and that they affect long belts which are continental or even world-wide in their dimensions. It seems fairly safe to assume that the deformative movements evidenced in western Wyoming accorded with this principle, and were manifestations of a much more widespread disturbance, the effects of which should be recognized in adjacent states. It is also self-evident that any such widespread disturbance would cause notable changes in the relief of the land, and would revolutionize the physiographic activities of the region so affected. These changes should now be found in the unconformities or in sudden changes in the character of sediments.

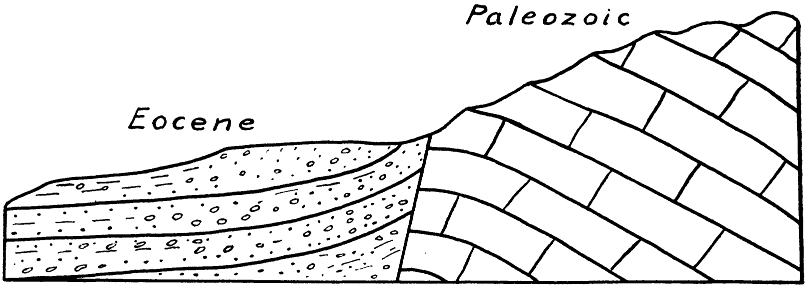

FIG. 10

In the Coast Ranges of California, Arnold and others appear to have shown beyond reasonable doubt that sedimentation prevailed rather generally and without notable interruption from the early Eocene to about the middle of the Miocene as those epochs are now generally correlated, but that near the middle of the Miocene the Tertiary beds were folded strongly so that the late Miocene sediments now rest with marked discordance upon the early Miocene and older strata. In central Washington, Willis, Smith, and Calkins have likewise shown that rocks containing early Miocene plants are highly folded and intruded by granites, and that upon their trunkated edges late Miocene lavas and sedimentary beds lie with but little change in their original attitude. In the Grand Canyon region of Arizona the studies of Huntington, Goldthwait, and others lead them to the conclusion that the conspicuous faults of the plateau region were begun long before the late volcanic eruptions, but also long after the gentle folding of the Cretaceous beds. There have also been subsequent movements along the same fractures. A broad study of the Middle Tertiary disturbance has

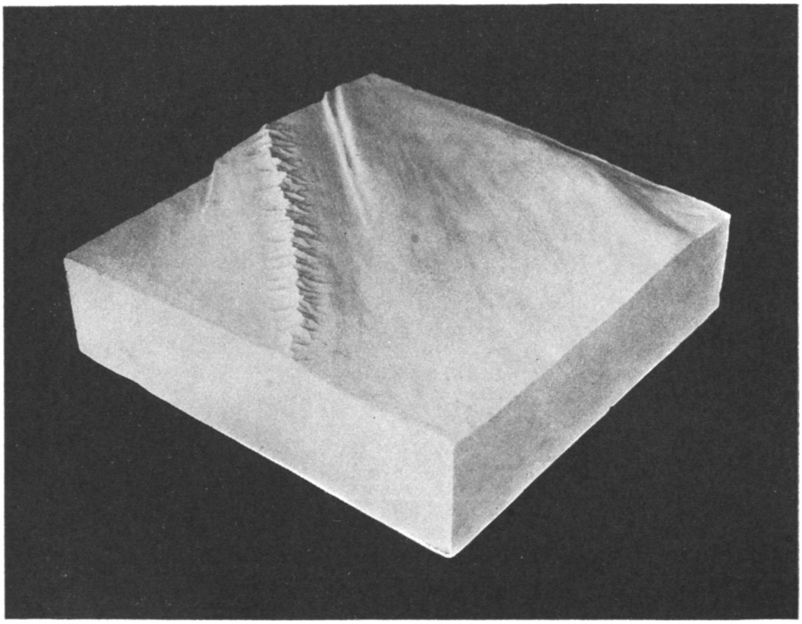

FIG. 11

recently been made by Mr. Hyrum Schneider, and recorded in his manuscript thesis for the M.A. degree at the University of Wisconsin in 1911 (not published). He concludes that the Middle Miocene disturbance affected all of the Cordilleran region, being expressed as folding along the Pacific coast and in Washington, but chiefly by warping and faulting in the Rocky Mountain province.

To summarize these considerations, it may be said then that the sedimentary formations deposited in the early part of the Tertiary period were afterward very gently folded and broken along a few scattered normal faults (see Fig. 11), and that the event took place in the midst of Tertiary time and probably in the middle of the Miocene epoch. Inasmuch as the Tertiary beds almost everywhere dip away from the anticlinal ranges and toward the synclinal basins, it seems evident that the mid-Tertiary deformation merely emphasized the structures produced at the close of the Cretaceous. The faults do not, however, in all cases follow these older structures, for in the Teton Range the original Gros Ventre anticline, which had a northwest-southeast trend, is diagonally transected by several large north-south faults.

[*To be continued*]